NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 2024

SOUND MEASUREMENTS FOR FIVE SHROUDED PROPELLERS

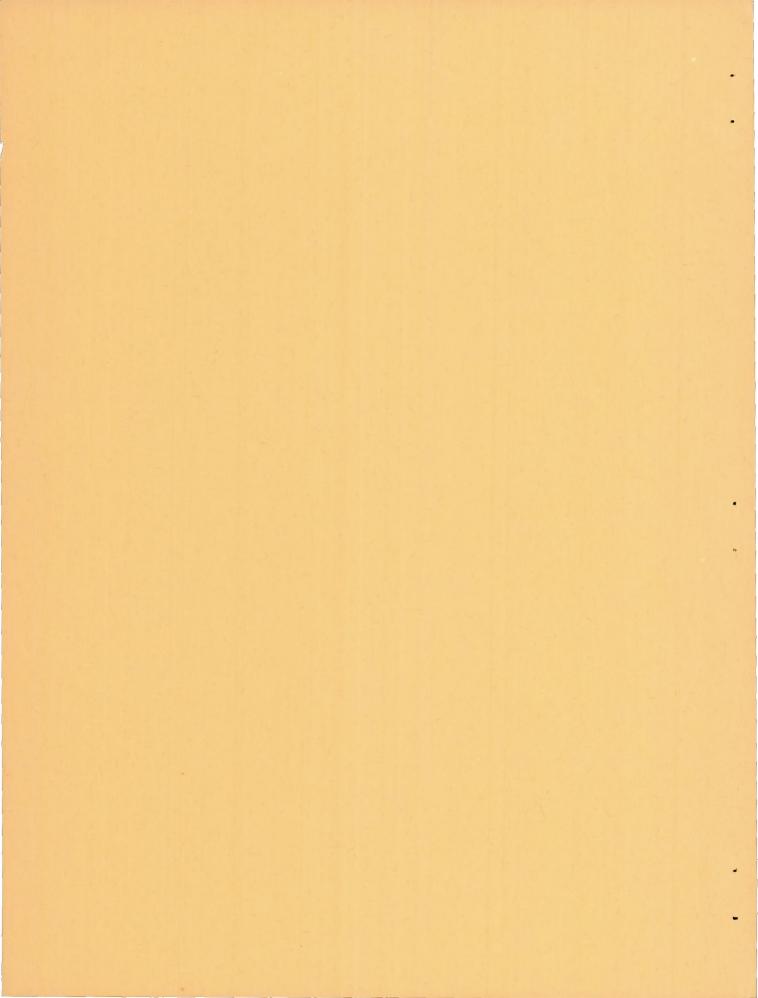
AT STATIC CONDITIONS

By Harvey H. Hubbard

Langley Aeronautical Laboratory Langley Air Force Base, Va.



Washington April 1950



NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 2024

SOUND MEASUREMENTS FOR FIVE SHROUDED PROPELLERS

AT STATIC CONDITIONS

By Harvey H. Hubbard

SUMMARY

Sound—pressure measurements at static conditions are reported for five shrouded propellers and are compared with those for an unshrouded propeller of the same diameter operating at approximately the same rotational speed and power.

The maximum total sound pressure produced by a two-blade shrouded propeller is found to vary approximately from one-half to twice as much as that for a two-blade unshrouded propeller, depending on whether the flow at the shroud surface is unseparated or separated, respectively. During conditions of unseparated flow the higher harmonics of rotational sound are greatly attenuated, the vortex noise produced is at a minimum, and the resulting sound is predominantly of low frequency. For the separated flow condition, all rotational—sound frequencies are reinforced, the vortex noise is much greater, and an unpleasant high—frequency sound results.

As is the case with unshrouded propellers, an increased number of blades and a reduction in tip speed tend to reduce the sound pressures.

The shroud chord is found not to be critical except insofar as the aerodynamic considerations are affected. Tip clearances of less than 1 percent of the diameter are found to be satisfactory when sound alone is considered. In general, if the shroud-propeller unit satisfies aerodynamic requirements, good sound characteristics will also be obtained.

INTRODUCTION

The possibility of decreasing the sound and increasing the thrust of a propeller by means of a shroud has been discussed in reference 1.

An analytical investigation and a series of wind-tunnel tests of a shrouded propeller were included in reference 2.

Recent static tests of a shrouded propeller (reference 3) have indicated that approximately twice as much static thrust was obtained at a given power coefficient as with an unshrouded propeller, chiefly because the unshrouded propeller was stalled, whereas the shrouded propeller was unstalled. During these tests the shroud-propeller unit was observed to run quietly at times and to be very noisy at other times. During noisy operation the flow was observed to be separated from the inner shroud surface at the leading edge and during quiet operation the flow was unseparated.

Since the shrouded propeller shows some promise aerodynamically for application to personal owner type of aircraft and because few, if any, sound measurements have been reported on shrouded propellers, it seemed desirable to investigate experimentally the sound produced by them.

Static tests were made for a two-blade propeller operating in four different shrouds and, in addition, a limited number of tests were made with a five-blade shroud unit. The sound data obtained are compared with the sound from an unshrouded propeller operating at the same rotational speed and power.

SYMBOLS AND DEFINITIONS

| R | propeller tip radius, feet |
|----|---|
| r | station radius, feet |
| Ъ | section chord, feet |
| D | propeller diameter, feet |
| h | section thickness, feet |
| T | thrust developed by shroud, pounds |
| PH | power, horsepower |
| p | root-mean-square sound pressure for a given harmonic, dynes per square centimeter |
| p | root-mean-square total sound pressure, dynes per square centimeter |
| | |

0.75

| N | propeller rotational speed, rpm |
|------------|---|
| Mt | tip Mach number |
| d | tip clearance, feet |
| m | order of harmonic |
| В | number of blades |
| s | distance, feet |
| θ | angle measured from axis of rotation, degrees (00 in front) |
| β | blade angle, degrees |
| Subscript: | |

measured at r = 0.75R

The terms "noise," "sound," and "sound pressure" are used synony-mously.

The rotational noise of a propeller is the noise due to the steady aerodynamic forces on the blades. The frequencies are integral multiples of the fundamental frequency of blade passage (rotational frequency multiplied by the number of blades), and the pressures are a maximum slightly behind the plane of rotation.

The vortex noise is the propeller noise due to the unsteady forces on the propeller blade. The pressures are a maximum on the axis of rotation, and the frequencies are random.

APPARATUS AND METHODS

Static tests were conducted for the measurement and analyses of the sound emission of five different propeller—shroud combinations. Tests were made for a two—blade propeller with the four different shrouds described in tables I to IV, for a two—blade unshrouded propeller, and for one five—blade shrouded configuration. Most of the tests were made with the shroud—propeller unit of figure 1 which consists of shroud B (see table II) and the two—blade propeller because this combination gave consistent results and allowed the propeller—plane position to be adjusted.

The two-blade 4-foot-diameter propeller used in the tests was designed for shroud operation at a forward speed of about 120 miles per hour and had Clark Y blade sections. The blade-form curves are given in figure 2(a). This propeller was designed to operate at a speed of 3300 rpm and a blade angle $\,\beta_{0.75}\,$ of 21.5° and at these conditions in static tests the power absorbed was near the maximum available from the drive motor.

The five-blade 4-foot-diameter propeller incorporated the same blades as were used for the tests in reference 3, and the blade-form curves are shown in figure 2(b). This propeller was operated in shroud B at approximately the same rotational speed and power as the two-blade propeller for comparison of results.

The unshrouded two-blade propeller had rounded tips; whereas the shrouded propellers had squared tips. In all other respects the unshrouded propeller was the same as the shrouded two-blade propeller.

Flow separation from the inside shroud surface near the nose occurred at low rotational speeds for all propeller—shroud combinations. This flow separation established the lower limit of the speed range for the test. The top speed for continuous operation was limited to approximately a tip Mach number of 0.60 by the power of the drive motor; however, a limited amount of data was taken at a tip Mach number of 0.73.

The test propellers were driven by a 200-horsepower, water-cooled, variable-speed electric motor. Power inputs to the drive motor in all tests were measured directly by means of a wattmeter and these readings were corrected by means of motor-efficiency data to determine the power input to the propeller. The motor was rigidly mounted on an outdoor test stand as shown in figure 1.

The shrouds were designed with a fairly large leading-edge radius, and the sections were set at a -4° angle of attack, as illustrated in figure 3, in the hope that the tendency for the flow to separate at the nose would be lessened for static conditions. Since size and weight, as determined principally by the chord, are of great importance, shrouds C and D with chords of 9.6 inches, shroud B with 19.2 inches, and shroud A with 28.8 inches were tested to evaluate the effect of chord on the sound emission. Differences in the airfoil section, leading-edge radius, and so forth, which were introduced in an attempt to help stabilize the flow, were also present in this series of shrouds as indicated in the following paragraph.

Shroud A ordinates, as given in table I, were obtained by modifying the NACA 4312 airfoil section to increase the nose radius by 50 percent. From the 30-percent-chord station to the trailing edge the ordinates are those of the NACA 4312 section and ahead of the 30-percent station they

are greater than the normal NACA 4312 ordinates. The same type of modification, as indicated in tables II and III, was made to the NACA 4315 and NACA 4318 ordinates to obtain the section of shroud B and shroud C, respectively. The leading-edge radius for shroud D was made the same as for shroud B by increasing the normal leading-edge radius of the NACA 4318 airfoil section by 109 percent, as shown in table IV. Shrouds C and D offer a comparison, respectively, between a nearly conventional airfoil with one that has a much larger leading-edge radius than normal.

The shroud units were normally operated with the propeller plane at 40 percent of the chord, measured from the leading edge. At this station, which was at the minimum shroud diameter, the propeller tip clearance was 3/32 inch. One propeller—shroud combination was operated also with the propeller plane at the 32— and 48—percent stations for comparison. At the 40—percent station the blades were progressively shortened in a series of tests to evaluate the effect of increasing the propeller tip clearance.

Root-mean-square sound pressures were measured by a Massa Laboratories Model GA-1002 sound-pressure-measurement system calibrated to read directly in dynes per square centimeter. The microphone was placed at ground level to ensure maximum pickup of all frequencies at a distance of 30 feet from the propeller hub and at various angles θ from the propeller axis of rotation (0° in front of propeller). Pressure amplitudes (rms) of the first four harmonics of the rotational sound were measured with a Hewlitt-Packard harmonic wave analyzer adjusted to a band width of 100 cycles per second. Total sound measurements were also made for each test condition.

No propeller—thrust data were measured; however, pressure measurements on the shroud surfaces, from which shroud thrust was calculated, were recorded by means of a multiple manometer. These pressure data were measured at one section and are assumed to apply all around the shroud periphery.

For these static tests, wind direction was critical in establishing the air flow in the shroud. Cross winds and tail winds generally caused a separation of the air flow on parts of the shroud surface, and head winds generally assisted in establishing unseparated flow. Flow conditions were observed by means of tufts located around the periphery of the shroud on the inside surface near the leading edge.

RESULTS AND DISCUSSION

As observed in earlier shroud tests (reference 3) the sound produced by a shroud-propeller unit is found to be influenced by the flow conditions at the shroud surface. In general, the sound produced by a given unit is less when the flow at the shroud surface is unseparated than when it is separated.

Total sound.— Measurements of the total sound pressures as shown in figure 4 give a comparison between the two-blade shrouded and the two-blade unshrouded propeller at the same rotational speed and power. At the angle of maximum sound ($\theta = 120^{\circ}$ approx.) the sound pressures produced vary approximately from one-half as much to twice as much as the unshrouded propeller, depending on the flow conditions. For the separated-flow condition, the vortex noise, which normally appears strongest on the propeller axis of rotation, is observed to be much increased, and the resulting sound is unpleasant. For the unseparated-flow condition, the vortex noise is apparently less, and the sound produced has a predominant low-frequency content.

An appraisal of the quality of the sound produced at these two flow conditions may be obtained from figure 5. Cathode—ray oscillograph pictures of the sound produced by a shrouded propeller are shown in figure 5(a) for unseparated flow and in figure 5(b) for separated flow resulting from a cross wind on a section of the shroud surface. Both photographs were taken at the same gain for comparison of amplitudes and the time interval between them is about 1 minute. It is apparent that the contribution of the high frequencies is much greater for the separated—flow condition.

Frequency analysis. A clearer picture of the frequency content of the total sound pressures represented by the three conditions of figure 4 can be obtained from figure 6. In this figure the relative amplitudes of the first four harmonics of rotational sound of a two-blade shrouded and unshrouded propeller are presented. All data were taken at the same rotational speed and power for comparison. Figure 6 indicates that the maximum rotational—sound amplitudes were not greater for a shrouded propeller than for an unshrouded propeller at the same rotational speed and power. A substantial amplitude reduction for all rotational—sound frequencies may be realized, however, if favorable flow conditions exist in the shroud, and the amount of such a reduction depends on the order of the harmonic, the amplitudes of the higher harmonics being reduced by the greater amount.

Shroud chord. In order to determine the effect of shroud chord on the total sound, a limited number of tests were made with the same propeller in combination with shrouds A, C, and D. Data for shroud B are reproduced from figure 4 for comparison and these results are shown in figure 7.

All data were taken when unseparated flow had been established, except in shroud C for which apparently the unseparated—flow condition could not always be realized. It is apparent from the good agreement of the data for shrouds A, B, and D, which have chords of 28.8, 19.2, and 9.6 inches, respectively, that, in the range tested, the chord is not a significant parameter in sound generation. Aerodynamically, however, shrouds A and B were much more stable and produced a greater thrust than shrouds C and D. Shroud D had fluctuating—flow conditions which caused a thrust variation and this variation in turn excited axial vibrations of the shroud. These flow fluctuations were such as to prevent the evaluation of shroud thrust at the unseparated—flow condition. In general, then, if the shroud is operating at its best aerodynamically, it will also produce the least sound and the sound will not be affected greatly by the shroud dimensions.

Tip clearance.- In order to evaluate the effect of propeller tip clearance on the sound produced by a shroud unit, a series of tests was made with shroud B, in which the propeller blades were progressively shortened. Sound pressures were measured at four points ($\theta = 0^{\circ}$, 45°, 90°, and 120°) and were averaged to give the values plotted for the tipclearance ratios of figure 8. In addition, the measured power and shroud thrust estimated from pressures measured on the shroud surface are given for each operating condition. As the tip-clearance ratio is increased (that is, the blades are shortened) the shroud thrust drops off rapidly; whereas the sound does not change appreciably for tip-clearance ratios up to about 0.01. At greater tip-clearance ratios the sound pressures increase rapidly and apparently approach those for an unshrouded propeller. A limited number of tests were made with the propeller position adjusted to stations of 48 and 32 percent of the chord to compare these results with results obtained at the normal 40 percent or minimum section of the shroud. Both of these adjustments involved a change in tip clearance and the results indicated the same trend shown in figure 8.

Tip speed.— Tests in the tip Mach number range 0.45 to 0.73 indicated that the pressure amplitude of the fundamental frequency and second harmonic of a two—blade shrouded propeller increased as the 4.5 power and the 5.5 power of the tip speed, respectively, as shown in figure 9. These results are in agreement with those obtained from similar tests of unshrouded propellers (reference 4) and indicate that the laws relating tip speed and sound pressure are approximately the same for shrouded and unshrouded propellers.

Number of blades.— Rotational—sound data obtained with a two-blade and five-blade shrouded propeller, operating at the same rotational speed and power. are shown in figure 10. Data obtained with the five-blade propeller (mB = 5) are consistent with those for the two-blade propeller (mB = 2, 4, and 6). As in reference 4, it may be assumed that mB values

of 2, 4, 5, and 6 represent the fundamental frequencies of the rotational sound generated by two-, four-, five-, and six-blade propellers. Figure 10 shows, in general, that as the number of blades is increased, the rotational sound is decreased much the same as is indicated in reference 4 for an unshrouded propeller.

Figure 11 shows a comparison of the total sound emission of a two- and a five-blade shrouded propeller at the same rotational speed and power. The sound pressures, except those near the axis of rotation, are reduced for the larger number of blades; however, this reduction is less than the rotational—sound measurements of figure 10 would indicate. Thus, the data of figures 10 and 11 show that vortex noise is an important part of the total for the five-blade propeller. This finding is in agreement with results of tests on unshrouded multiblade propellers reported in reference 5.

Analysis.— An attempt was made to apply the Gutin analysis (references 5 and 6), in which the noise is divided into its torque and thrust components and which is useful in predicting the sound from an unshrouded propeller, to the shrouded case. This analysis shows that a decrease in thrust causes a decrease in rotational sound. It was found, however, that the rotational-sound-pressure reductions indicated in figure 6 could not be accounted for by use of this analysis. It is concluded that these sound-pressure reductions are not wholly the result of thrust relief of the propeller.

CONCLUSIONS

Sound—pressure measurements at static conditions of five shrouded propellers indicated the following conclusions:

- l. Maximum total sound pressure produced by a two-blade shrouded propeller may vary approximately from one—half to twice as much as that for a two-blade unshrouded propeller, depending on the flow conditions inside the shroud. In general, the sound produced is a minimum and has a predominant low-frequency content when the flow at the shroud surface is unseparated. At the separated-flow condition, sound pressures are a maximum, all rotational frequencies are strengthened, and much vortex noise is generated.
- 2. If shroud parameters, such as tip clearance, chord, and so forth, satisfy the aerodynamic requirements, in general, good sound characteristics will also be obtained. Tip clearances of less than 1 percent of the diameter are found to be satisfactory when sound alone is considered. The chord is not a significant parameter in sound generation.

3. The polar distribution of sound and the sound variation as a function of tip speed are approximately the same as for an unshrouded propeller.

4. An appreciable reduction of the maximum total sound pressure may be achieved by an increase in the number of propeller blades for a given operating condition. As the number of blades is increased, the rotational sound decreases markedly and the vortex noise increases to the extent that it comprises a large part of the total sound.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Air Force Base, Va., October 28, 1949

REFERENCES

- 1. Munk, Max M.: Silencing of Propellers by Thrust Relief. Aero Digest, vol. 33, no. 4, Oct. 1938, pp. 67 and 79.
- 2. Krüger, W.: On Wind Tunnel Tests and Computations Concerning the Problem of Shrouded Propellers. NACA TM 1202, 1949.
- 3. Platt, Robert J., Jr.: Static Tests of a Shrouded and an Unshrouded Propeller. NACA RM L7H25, 1948.
- 4. Deming, Arthur F.: Propeller Rotation Noise Due to Torque and Thrust. NACA TN 747, 1940.
- 5. Hicks, Chester W., and Hubbard, Harvey H.: Comparison of Sound Emission from Two-Blade, Four-Blade, and Seven-Blade Propellers. NACA TN 1354, 1947.
- 6. Gutin, L.: On the Sound Field of a Rotating Propeller. NACA TM 1195, 1948.

TABLE I. - SHROUD A SECTION COORDINATES

| Airfoil section | | | | | | NACA 4312 (modified) |
|------------------------------|--|--|--|--|--|----------------------|
| Maximum thickness | | | | | | 12 percent of chord |
| Leading-edge radius | | | | | | 0.685 inch |
| Slope of leading-edge radius | | | | | | 0.267 |
| Chord | | | | | | 28.8 inches |

| | Inner | surface | | Outer surface | | | | | | | |
|--|--|---|--|---|---|--|--|--|--|--|--|
| Stat | ion | Ordina | ite | Stat | Station Ordin | | | | | | |
| Percent | Inches | Percent thickness | Inches | Trahag | Percent thickness | Inches | | | | | |
| 0.671 1.748 4.093 6.559 9.089 14.253 19.481 24.735 30.000 40.095 50.173 60.223 70.239 80.213 90.141 95.085 100.000 | 0.193 .503 1.179 1.889 2.618 4.105 5.611 7.124 8.64 11.547 14.45 17.344 20.229 23.101 24.961 27.384 28.8 | 2.590 3.714 5.305 6.457 7.348 8.601 9.389 9.849 10.000 9.724 8.967 7.826 6.349 4.573 2.500 1.353 | 0.746 1.07 1.528 1.86 2.116 2.477 2.704 2.837 2.88 2.801 2.582 2.254 1.829 1.317 .72 .39 | 1.829 3.252 5.907 8.441 10.911 15.747 20.519 25.265 30.000 39.905 49.827 59.777 69.761 79.787 88.554 94.915 100.000 | 0.527 .937 1.701 2.431 3.142 4.535 5.909 7.276 8.64 11.493 14.350 17.216 20.091 22.979 25.504 27.336 28.8 | -1.938 -2.436 -2.861 -2.957 -2.904 -2.601 -2.279 -2.000 -1.886 -1.621 -1.296961655378251 0 | -0.558702824852836749656576543467373277189109072 | | | | |

NACA

TABLE II. - SHROUD B SECTION COORDINATES

| Airfoil section | | | | | | | | NACA 4315 (modified) |
|------------------------------|---|-----|---|--|--|--|---|----------------------|
| Maximum thickness | | | | | | | | 15 percent of chord |
| Leading-edge radius | 0 | | | | | | | 0.713 inch |
| Slope of leading-edge radius | | | | | | | | 0.267 |
| Chord | | . 0 | 0 | | | | 0 | 19.2 inches |

| | Inner | surface | | Outer surface | | | | | | | |
|--|--|---|---|---|---|--|---|--|--|--|--|
| Stat | ion | Ordina | ite | Stat | ion | Ordinate | | | | | |
| Percent chord | Inches | Percent thickness | Inches | Percent | Inches | Percent thickness | Inches | | | | |
| 0.527 1.560 3.866 6.323 8.861 14.066 19.352 24.669 30.000 40.119 50.216 60.279 70.298 80.267 90.176 95.106 100.000 | 0.101 .300 .742 1.214 1.701 2.701 3.716 4.736 5.76 7.703 9.641 11.574 13.497 15.411 17.314 18.260 19.2 | 3.156 4.483 6.326 7.633 8.629 10.002 10.847 11.339 11.500 11.175 10.290 8.965 7.263 5.227 2.859 1.552 0 | 0.606 .861 1.215 1.466 1.657 1.920 2.083 2.177 2.208 2.146 1.976 1.721 1.394 1.004 .549 .298 | 1.973 3.440 6.134 8.677 11.139 15.934 20.648 25.331 30.000 39.881 49.784 59.721 69.702 79.733 89.824 94.894 100.000 | 0.527 .660 1.178 1.666 2.139 3.059 3.964 4.864 5.76 7.657 9.559 11.466 13.383 15.309 17.246 18.220 19.2 | -2.504 -3.205 -3.882 -4.133 -4.185 -4.002 -3.737 -3.561 -3.561 -3.500 -3.337 -2.435 -1.875 -1.875 -1.309 -737 450 0 | -0.481615745794804768718684672641565468360251142086 | | | | |



TABLE III. - SHROUD C SECTION COORDINATES

| Airfoil section | | | | | | 0 | . NACA 4318 (modified) |
|------------------------------|---|--|---|---|---|---|------------------------|
| Maximum thickness | 0 | | 0 | | | | . 18 percent of chord |
| Leading-edge radius | | | | | | | |
| Slope of leading-edge radius | | | | 0 | 0 | | 0.267 |
| Chord | | | | | | | 9.6 inches |

| | | | | A Line 1 | | | | | | | |
|--|---|---|---|--|--|---|--|--|--|--|--|
| | Inner | surface | | Outer surface | | | | | | | |
| Stat | tion | Ordina | ate | Stat | ion | Ordinate | | | | | |
| Percent chord | Inches | Percent thickness | Inches | Percent chord | Inches | Percent thickness | Inches | | | | |
| 0 .382 1.382 3.639 6.088 8.633 13.880 19.222 24.603 30.000 40.142 50.259 60.335 70.358 80.320 90.211 95.128 100.000 | 0 .037 .132 .349 .584 .829 1.333 1.845 2.362 2.880 3.854 4.825 5.792 6.754 7.711 8.660 9.132 9.600 | 0 3.723 5.252 7.347 8.810 9.910 11.403 12.306 12.829 13.000 12.627 11.615 10.106 8.176 5.880 3.220 1.753 0 | 0 .357 .504 .705 .846 .951 1.095 1.181 1.232 1.248 1.212 1.115 .970 .785 .565 .309 .168 | 0 2.118 3.628 6.361 8.912 11.367 16.120 20.778 25.397 30.000 39.858 49.741 59.665 69.642 79.680 89.789 94.872 100.000 | 0 .203 .348 .611 .856 1.091 1.548 1.995 2.438 2.880 3.826 4.775 5.728 6.686 7.649 8.620 9.108 9.600 | 0 -3.071 -3.974 -4.903 -5.310 -5.466 -5.403 -5.196 -5.051 -5.000 -4.789 -4.269 -3.576 -2.788 -1.962 -1.098 651 0 | 0 295 382 471 510 525 519 485 480 460 410 343 268 105 063 0 | | | | |



TABLE IV .- SHROUD D SECTION COORDINATES

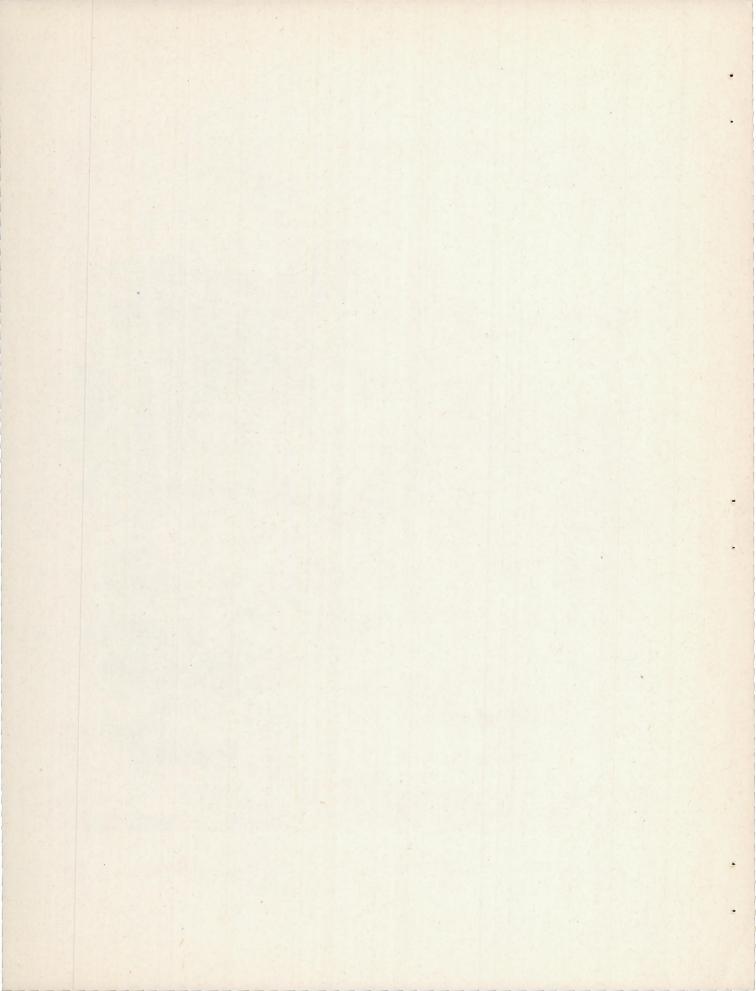
| Airfoil section | | | | | | | | 0 | NACA 4318 (modified) |
|------------------------------|---|---|---|---|--|---|---|---|----------------------|
| Maximum thickness | | | 0 | | | | | | 18 percent of chord |
| Leading-edge radius | | | | | | | | | 0.713 inch |
| Slope of leading-edge radius | 0 | ٥ | | 0 | | | 0 | | 0.267 |
| Chord | | | | | | 0 | | | 9.6 inches |

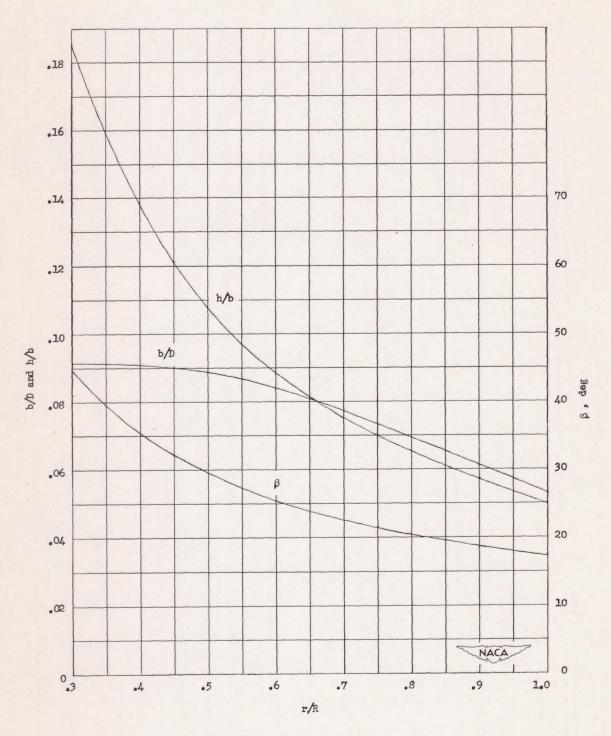
| Inner | surface | | Outer surface | | | | | | | |
|---|--|---|--|--|--|--|--|--|--|--|
| Station | Ordina | ite | Stat | ion | Ordinate | | | | | |
| Percent chord Inches | Percent thickness | Inches | Percent chord | Inches | Percent thickness | Inches | | | | |
| 0 .235 .023 1.182 .113 3.472 .333 5.970 .573 8.560 .822 13.859 1.331 19.217 1.845 24.603 2.362 30.000 2.880 40.142 3.854 50.259 4.825 60.335 5.792 70.358 6.754 80.320 7.711 90.211 8.660 95.128 9.132 | 0 4.297 6.030 8.103 9.396 10.323 11.562 12.364 12.830 13.000 12.627 11.615 10.106 8.176 5.880 3.220 1.753 0 | 0 .413 .579 .778 .902 .991 1.111 1.188 1.232 1.248 1.212 1.115 .970 .785 .565 .309 .168 | 0 2.265 3.818 6.528 9.030 11.440 16.141 20.783 25.397 30.000 39.858 49.741 59.665 69.642 79.680 89.789 94.872 100.000 | 0 .217 .367 .627 .867 1.098 1.549 1.995 2.439 2.880 3.826 4.775 5.728 6.686 7.649 8.620 9.108 9.600 | 0 -3.645 -4.752 -5.659 -5.896 -5.879 -5.562 -5.254 -5.000 -4.789 -4.775 -3.576 -2.788 -1.962 -1.098 -651 0 | 0 350 456 543 564 534 504 480 460 410 343 268 105 063 | | | | |





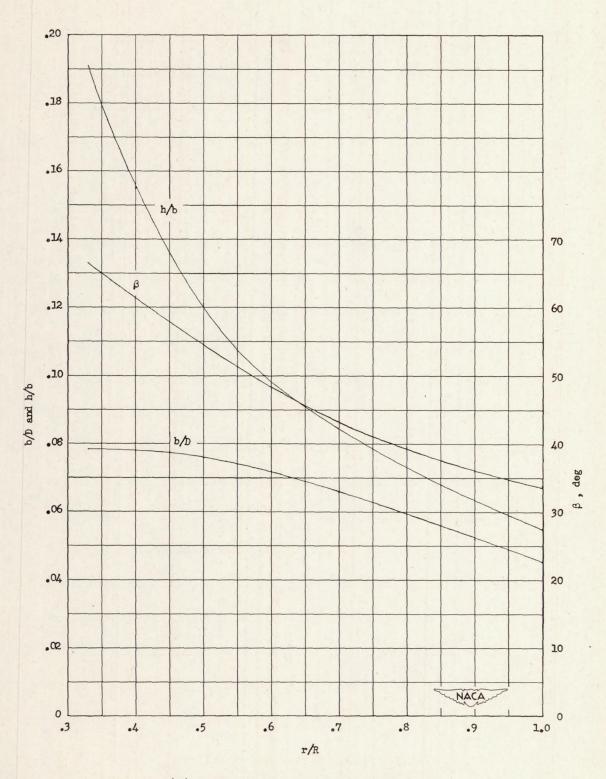
Figure 1. - Test installation (front view) of the shrouded two-blade propeller (shroud B).





(a) Two-blade shrouded propeller.

Figure 2.- Blade-form curves.



(b) Five-blade shrouded propeller.

Figure 2.- Concluded.

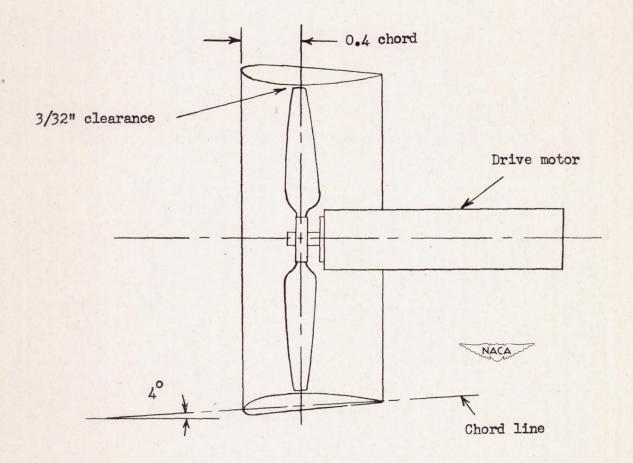


Figure 3.- Schematic view of shrouded-propeller test arrangement.

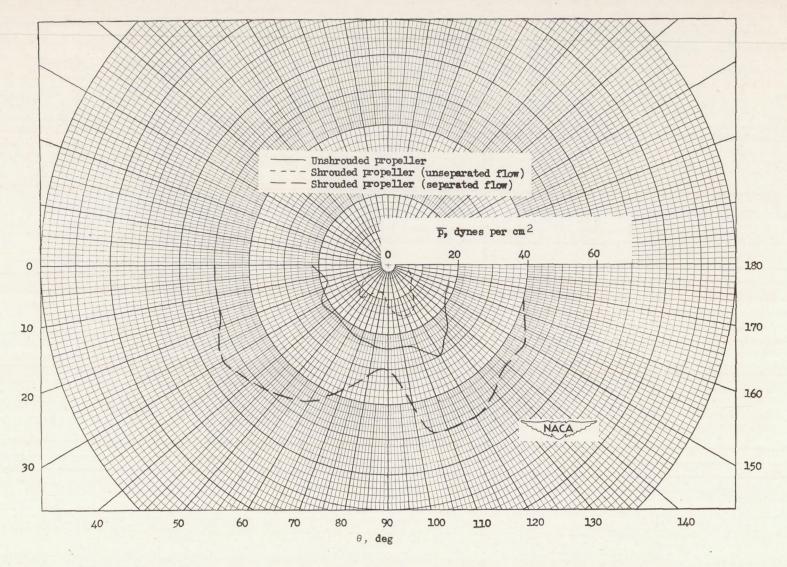


Figure 4.- Polar distribution of total sound produced by a shrouded and unshrouded two-blade propeller at approximately the same rotational speed and power. N = 3300 rpm; s = 30 feet; $P_{\rm H}$ = 68 horsepower.

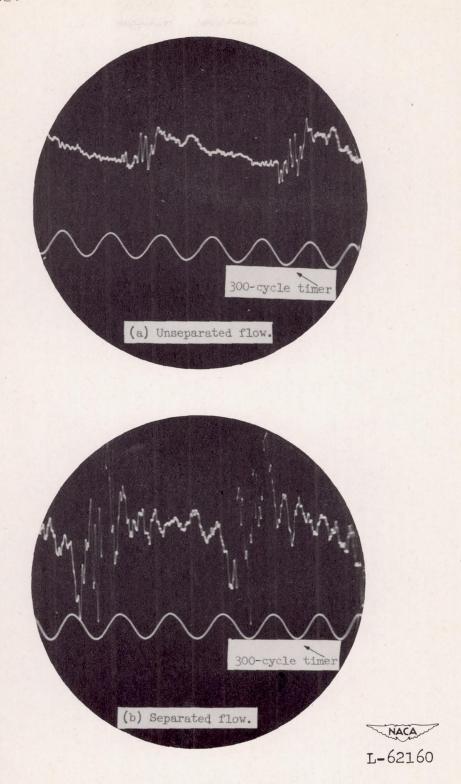
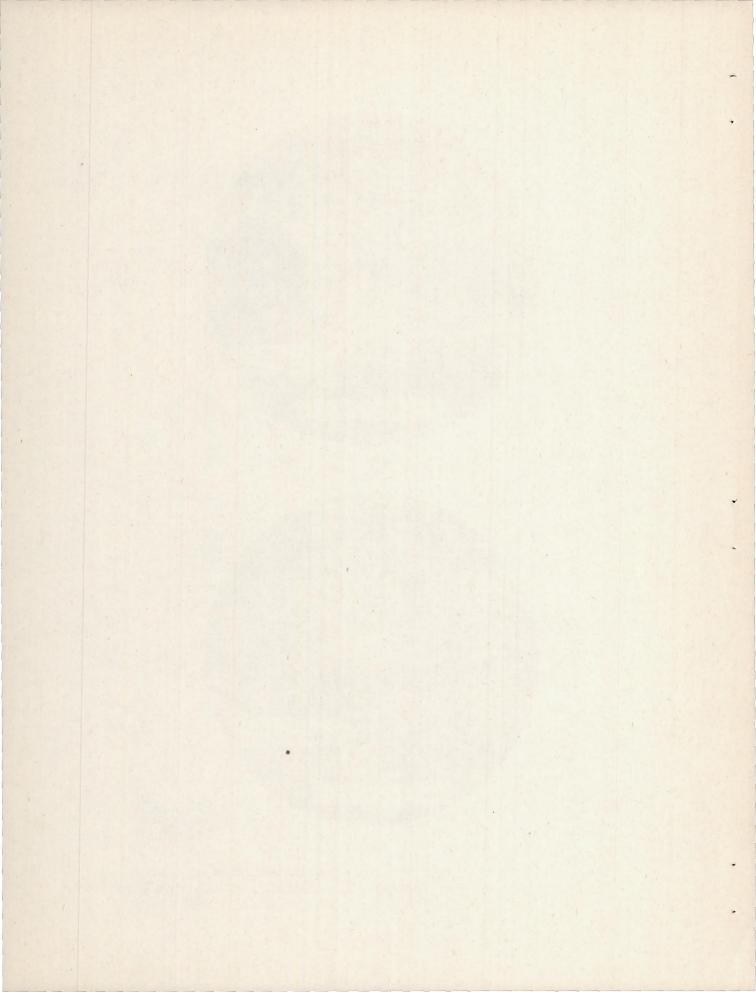


Figure 5.- Oscillograph records of sound emission of a two-blade shrouded propeller for two flow conditions inside the shroud. $\beta_{0.75} = 21.5^{\circ}$; $\theta = 120^{\circ}$; N = 3300 rpm; s = 30 feet.



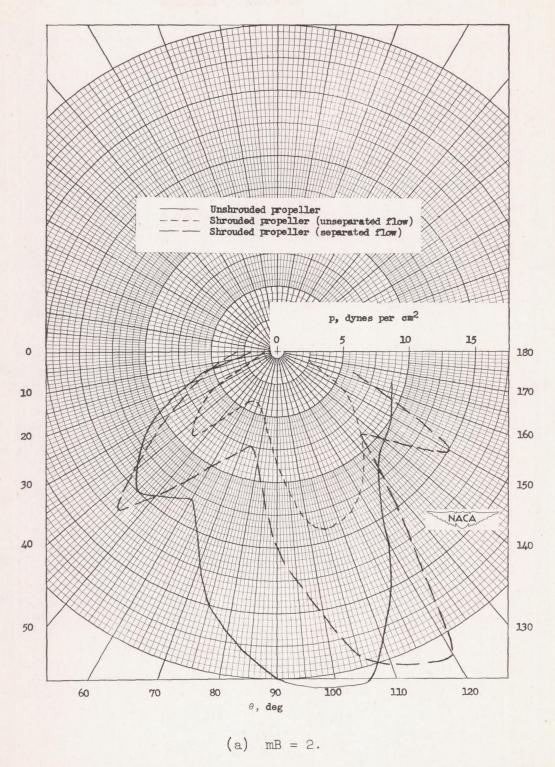


Figure 6.- Polar distribution of the first four harmonics of rotational sound of a two-blade shrouded and unshrouded propeller at approximately the same rotational speed and power. N=3300 rpm; s=30 feet; $P_{\rm H}=68$ horsepower.

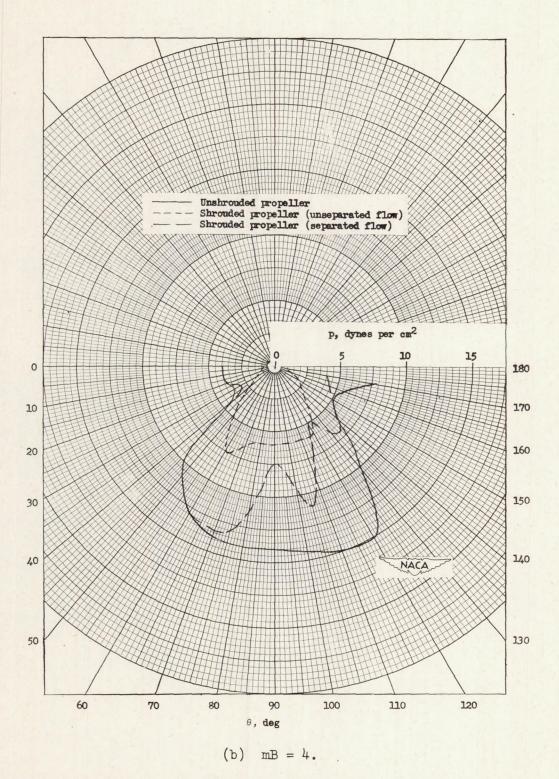


Figure 6.- Continued.

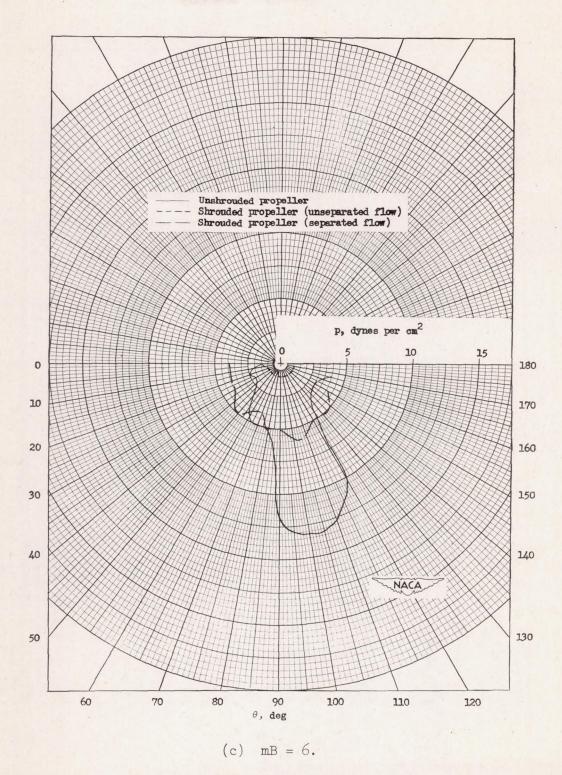


Figure 6.- Continued.

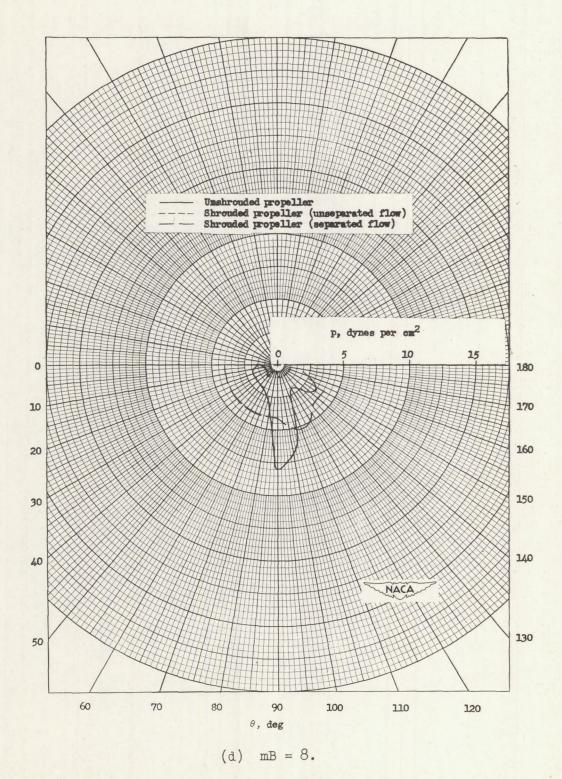


Figure 6.- Concluded.

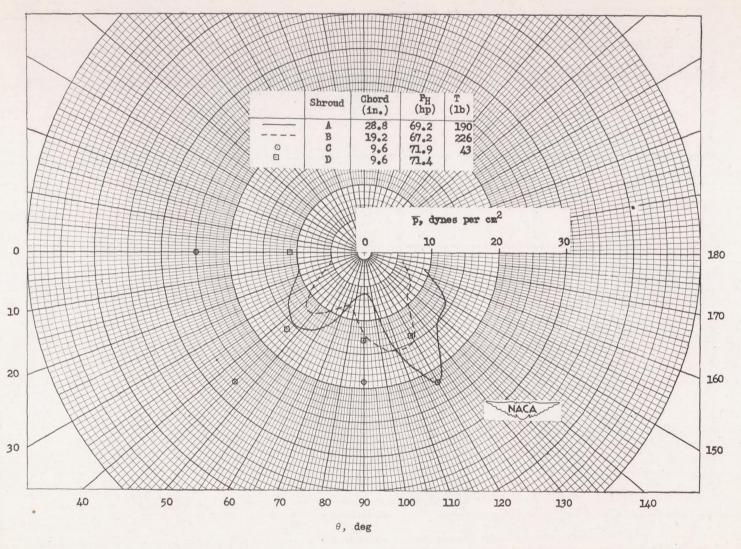


Figure 7.- Comparison of total sound generated by four shroud-propeller units. $\beta_{0.75}$ = 21.5°; N = 3300 rpm; s = 30 feet.

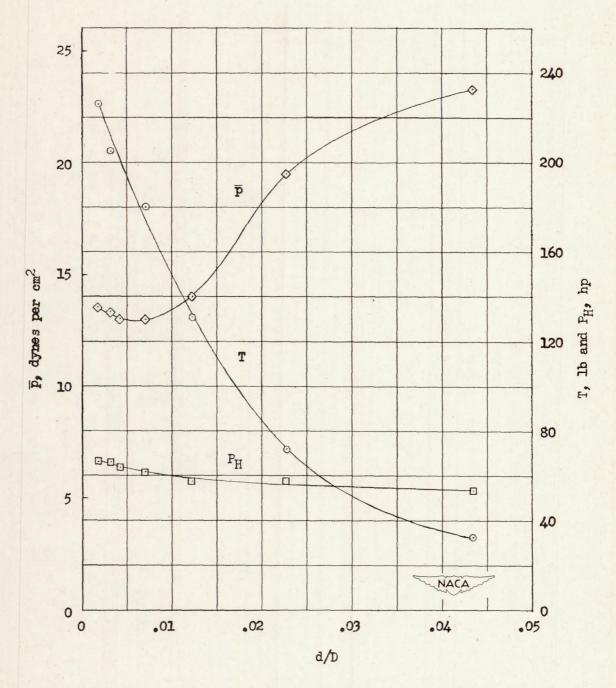


Figure 8.- Effect of tip-clearance ratio on power absorption, shroud thrust, and total sound emission of a shrouded propeller (shroud B). N = 3300 rpm; s = 30 feet.

29

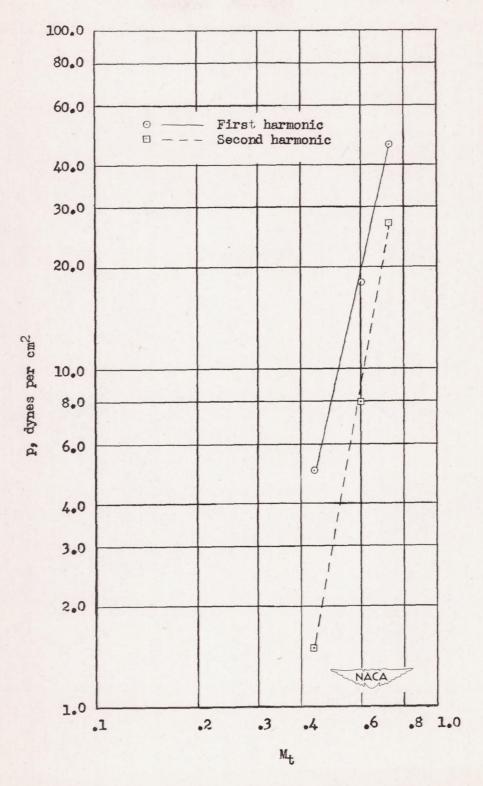


Figure 9.- Variation of pressure amplitude with tip Mach number for the first two harmonics of a two-blade shrouded propeller operating in shroud A. $\beta_{0.75} = 21.5^{\circ}$; $\theta = 120^{\circ}$; s = 30 feet.

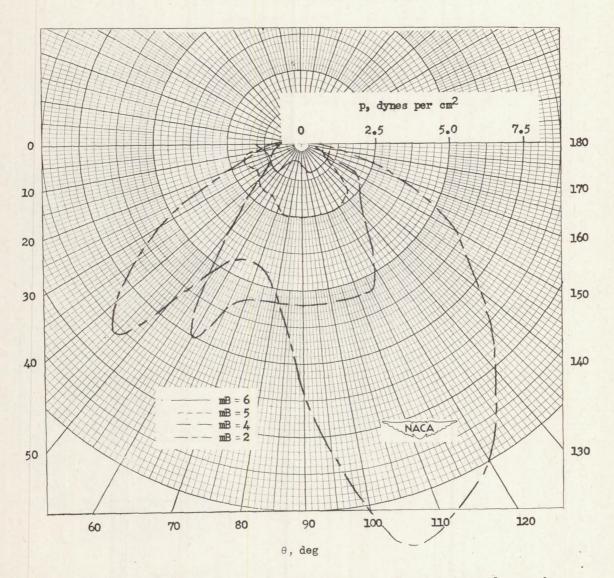


Figure 10.- Effect of number of blades on the rotational—sound emission of a shrouded propeller. N = 3300 rpm; s = 30 feet; $P_{\rm H}$ = 68 horsepower.

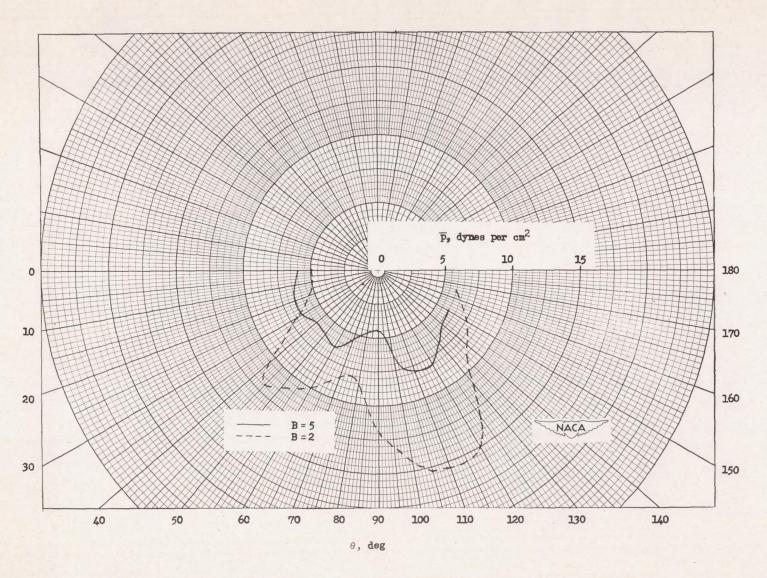


Figure 11.- Comparison of the total sound emission of two-blade and five-blade shrouded propellers at the same rotational speed and power. $M_{\rm t}$ = 0.60; s = 30 feet; $P_{\rm H}$ = 68 horsepower.

